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A systematic methodology for controller tuning in wastewater treatment plants

Mauricio Iglesias, Miguel; Jørgensen, Sten Bay; Sin, Gürkan

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Controller tuning in wastewater treatment plants

Miguel Mauricio-Iglesias
Sten Bay Jørgensen
Gürkan Sin

DTU Chemical Engineering
Department of Chemical and Biochemical Engineering

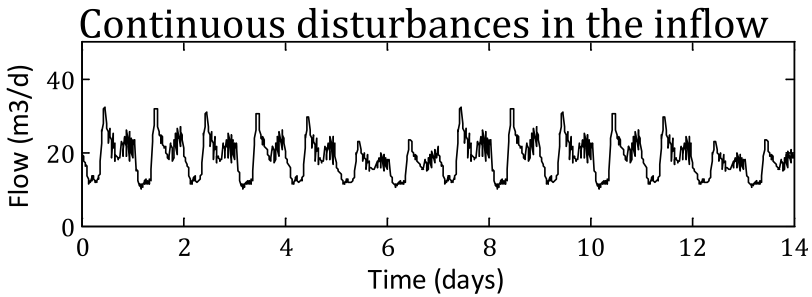
Introduction and motivation

Tuning a control loop is the adjustment of its control parameters to the optimum values for the desired control response

There is a large number of methods that can be used for tuning.

O'Dwyer, A. *Handbook of Controller Tuning Rules*
Åström, K. J. and Hägglund, T. *PID Controllers: Theory, Design and Tuning*

Wastewater treatment plants (WWTP) can be tuned according to any of those methods. They use mostly PI controllers



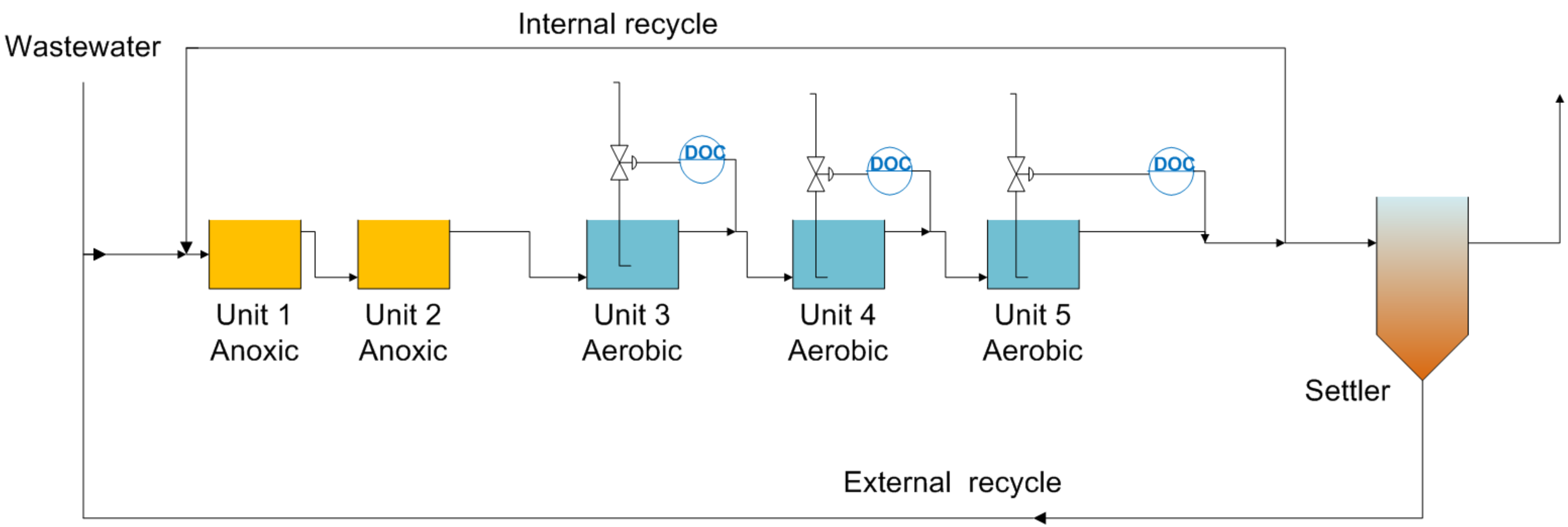
The purpose of this contribution is to use process engineering knowledge of WWTP and its influent dynamics to improve the tuning of the controllers!

Overview of the presentation

1) Presentation of the WWTP
2) Methodology. Example
3) Process review
4) Open loop analysis
5) Closed loop design
6) Evaluation
7) Conclusion

Model WWTP

Benchmark simulation model 1



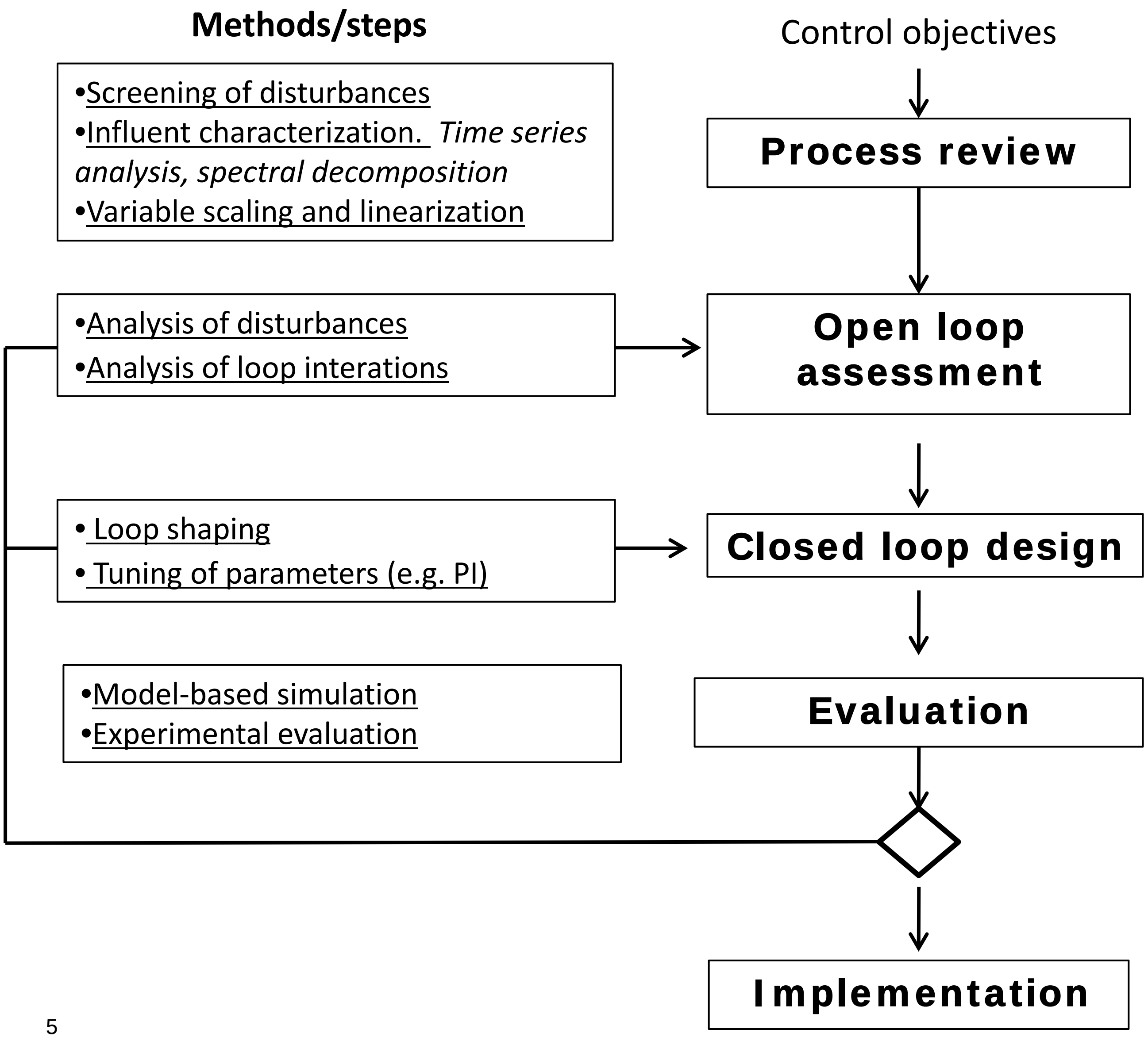
Provide basic information about the plant capacity.

Typically flow rate

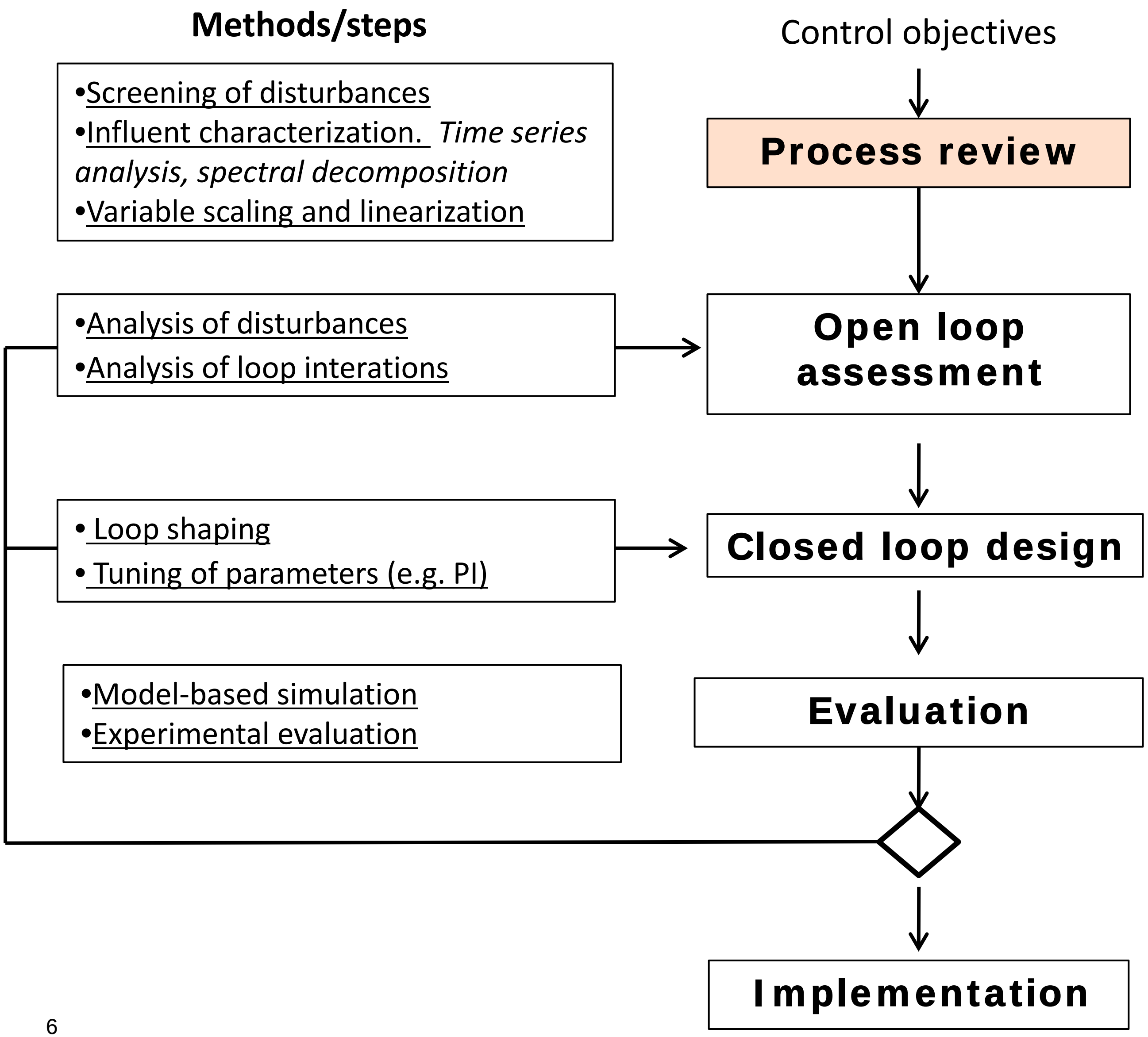
Typical effluent requirement.

Etc. This is

Methodology

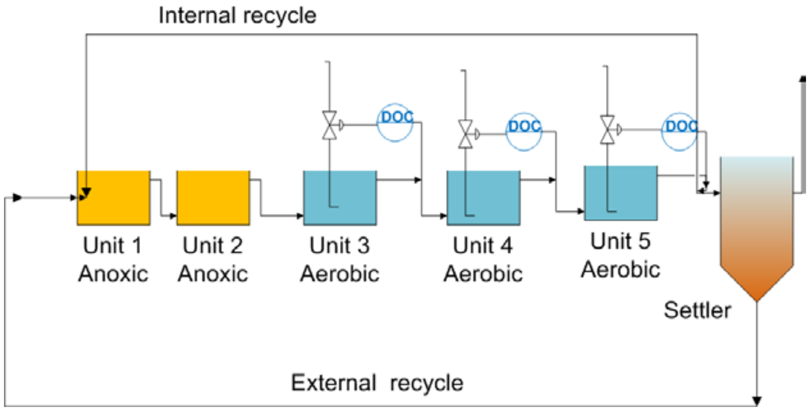


Methodology



Process review. Screening of disturbances

Wastewater



11 variables

-soluble inert organic matter	S_I
-readily biodegradable substrate	S_S
-particulate inert organic matter	X_I
-slowly biodegradable substrate	X_S
-active heterotrophic biomass	X_{BH}
-total ammonium nitrogen	S_{NH}
-soluble biodegradable organic nitrogen	S_{ND}
-part. biodegradable organic nitrogen	X_{ND}
-alkalinity	S_{ALK}
-total suspended solids	T_{SS}
-total flowrate	Q

Process review. Screening of disturbances

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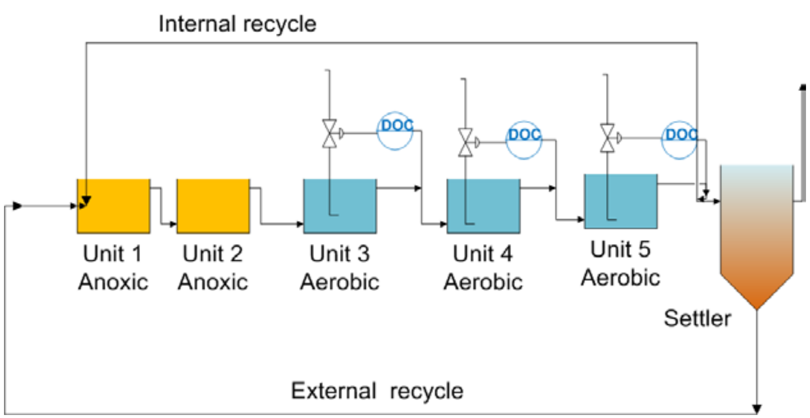
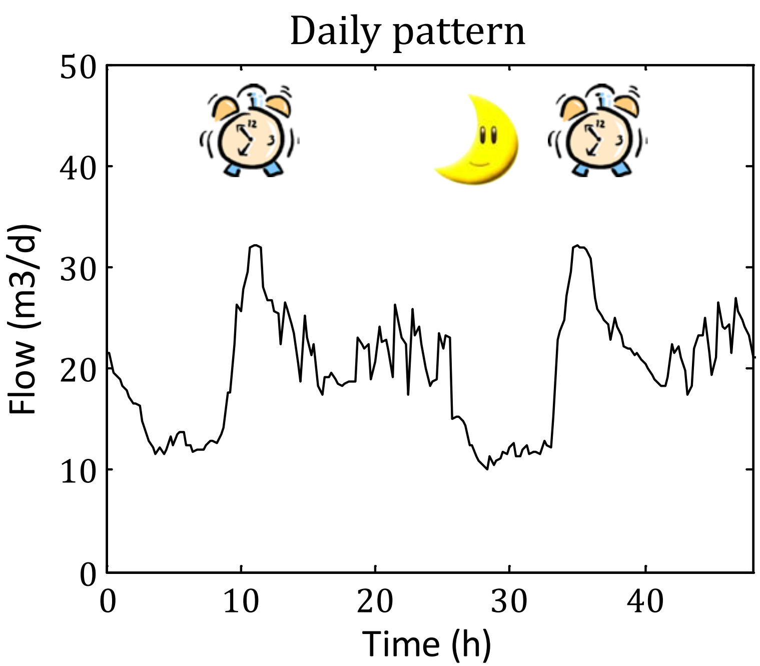
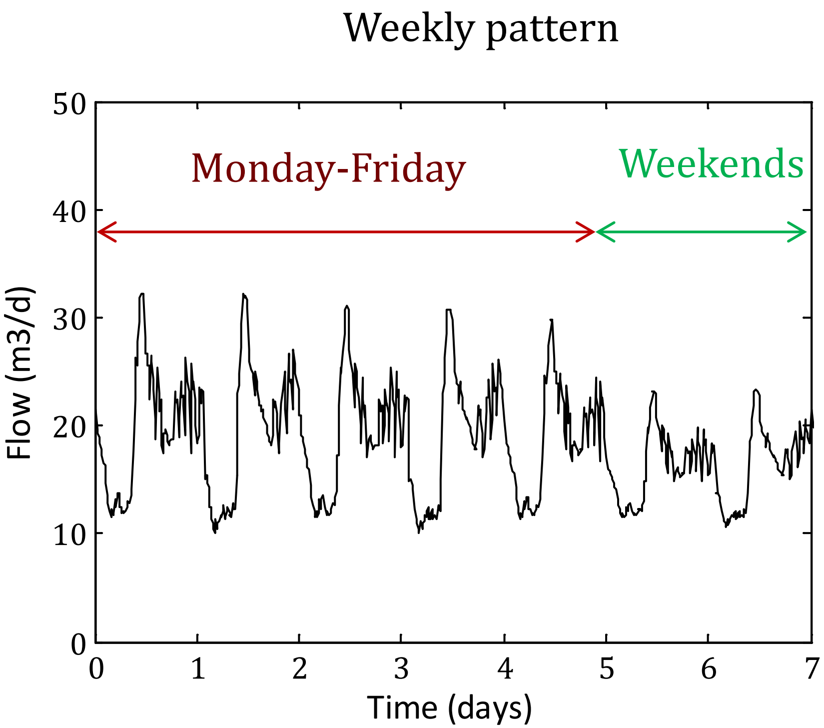


Sin et al. 2011

Process review. Influent characterization & dynamics

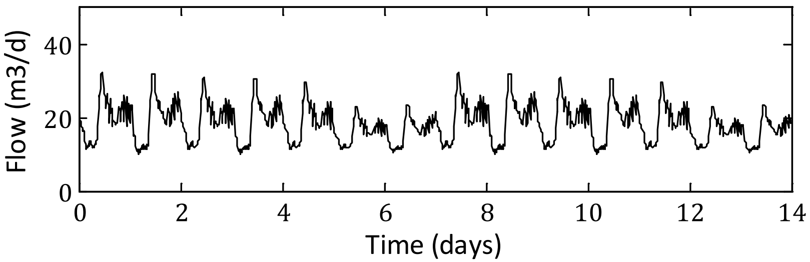
Dry weather



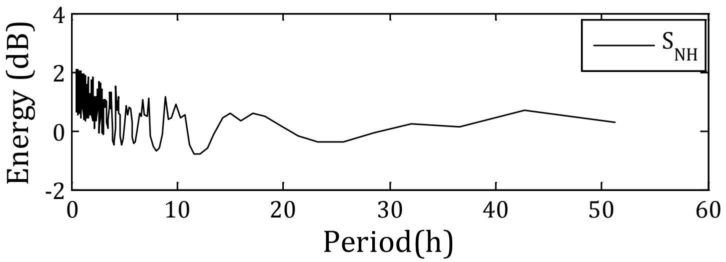


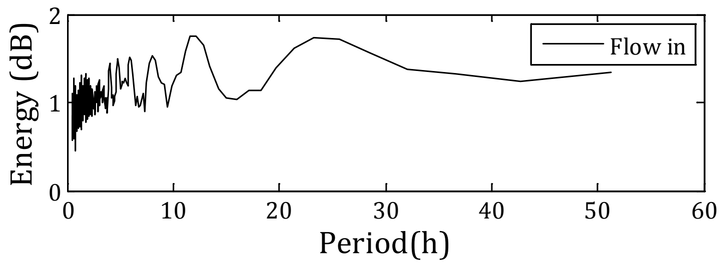
Gernaey et al. 2011

Process review. Influent characterization

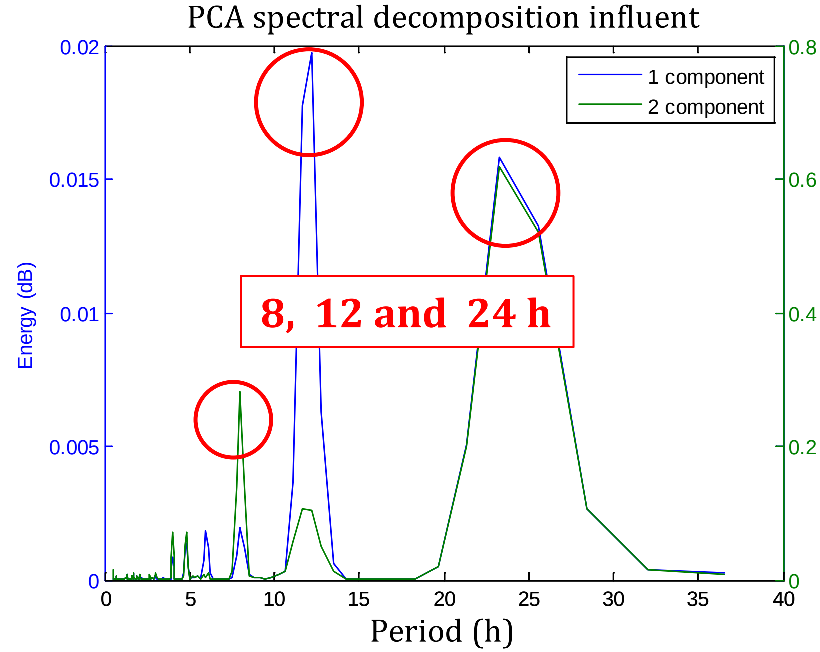


Spectral decomposition





Main periods associated with influent dynamics



Principal component analysis

Thornhill and Horch. 2007

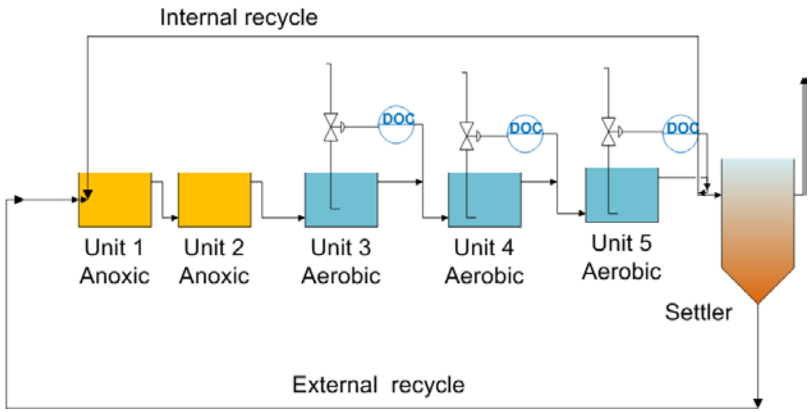
Process review. Variable scaling

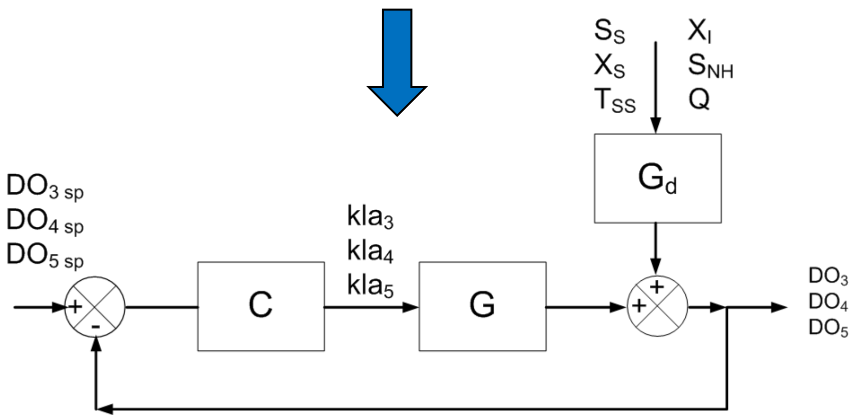
A number of criteria used depend critically on the scaling

Disturbances (d_{max}-d_{min}) for dry weather, rain and storm weather	Var.	S_I (g COD m^{-3})	S_S (g COD m^{-3})	X_I (g COD m^{-3})
	Value	30	65.2	45.6
	Var.	X_S (g COD m^{-3})	X_{BH} (g COD m^{-3})	S_{NH} (g N m^{-3})
	Value	193	26.5	30.1
	Var.	S_{ND} (g N m^{-3})	X_{ND} (g N m^{-3})	S_{ALK} (mol m^{-3})
	Value	6.5	10	7
	Var.	T_{SS} (g COD m^{-3})	Q (m^3 d^{-1})	
	Value	199	18446	
CVs Δy_{max}	Var.	D_{O3} (g O m^{-3})	D_{O4} (g O m^{-3})	D_{O5} (g O m^{-3})
	Value	0.1	0.1	0.1
MVs (u_{max}-u_{min})	Var.	kLa_3 (d^{-1})	kLa_4 (d^{-1})	kLa_5 (d^{-1})
	Value	360	360	360

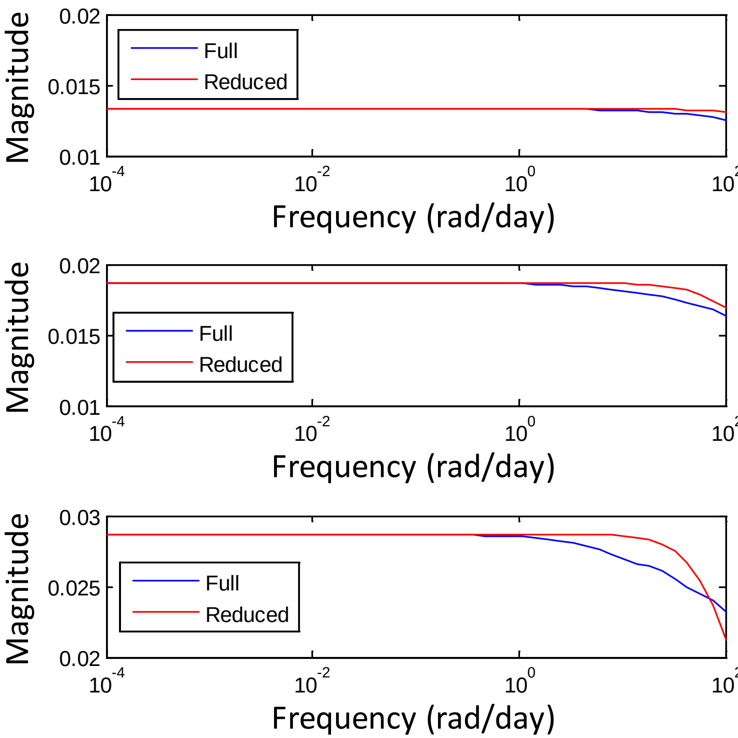
Skogestad and Postlethwaite 2007

Process review. Plant linearisation





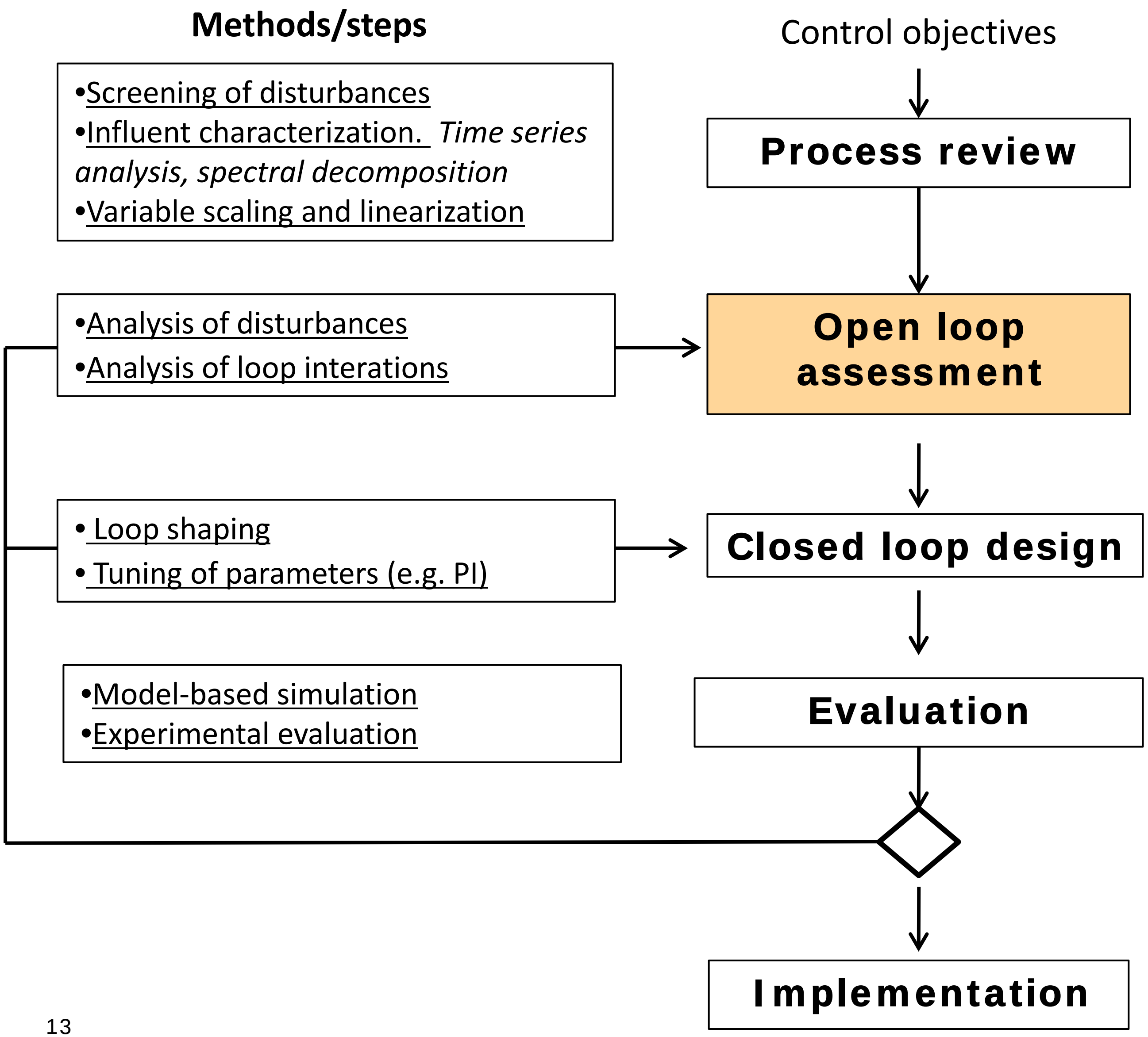
$$G = \begin{array}{c} DO_3 \\ DO_4 \\ DO_5 \end{array} \quad \frac{1}{13.8s+1} \begin{array}{c} \begin{array}{ccc} kla_3 & kla_4 & kla_5 \end{array} \\ \begin{bmatrix} \mathbf{47.9} & 0.92 & 1.97 \\ 16.7 & \mathbf{67.1} & 5.64 \\ 15.8 & 31.7 & \mathbf{103} \end{bmatrix} \end{array}$$



Full linear model (96 states)

Reduced linear model (1 state)

Methodology



Open loop assessment. Disturbances

Closed Loop Disturbance Gain (CLDG)

$$CDLG = \tilde{G}_{(s)} G^{-1}{}_{(s)} G_{d\,(s)}$$

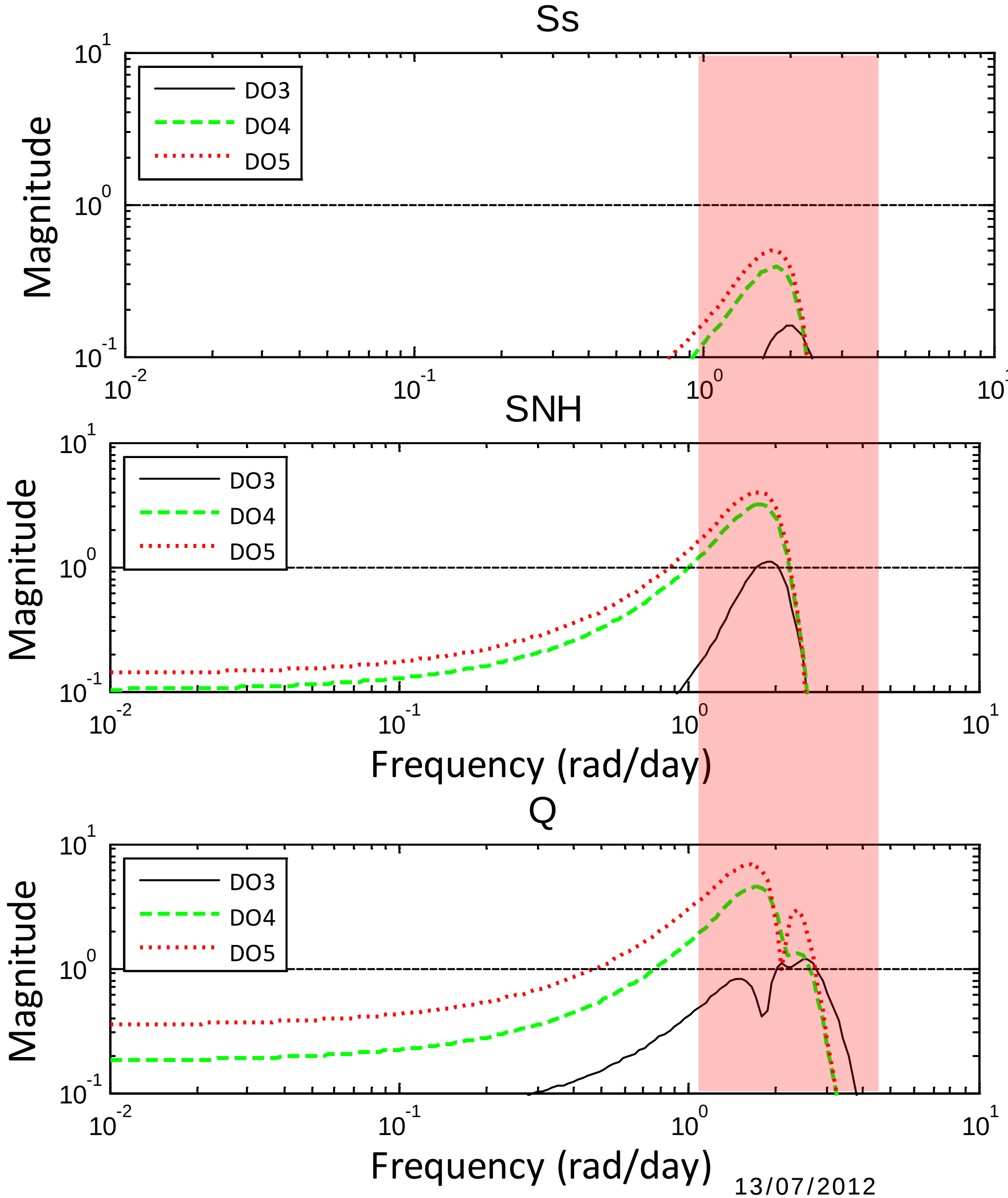
CLDG = $|\delta_i| < 1$

The disturbance effect is lower than Δy_{max}

CLDG = $|\delta_i| > 1$

The disturbance effect is higher than Δy_{max}
Need of control action!

$$|g_i c_i| > |\delta_i|$$



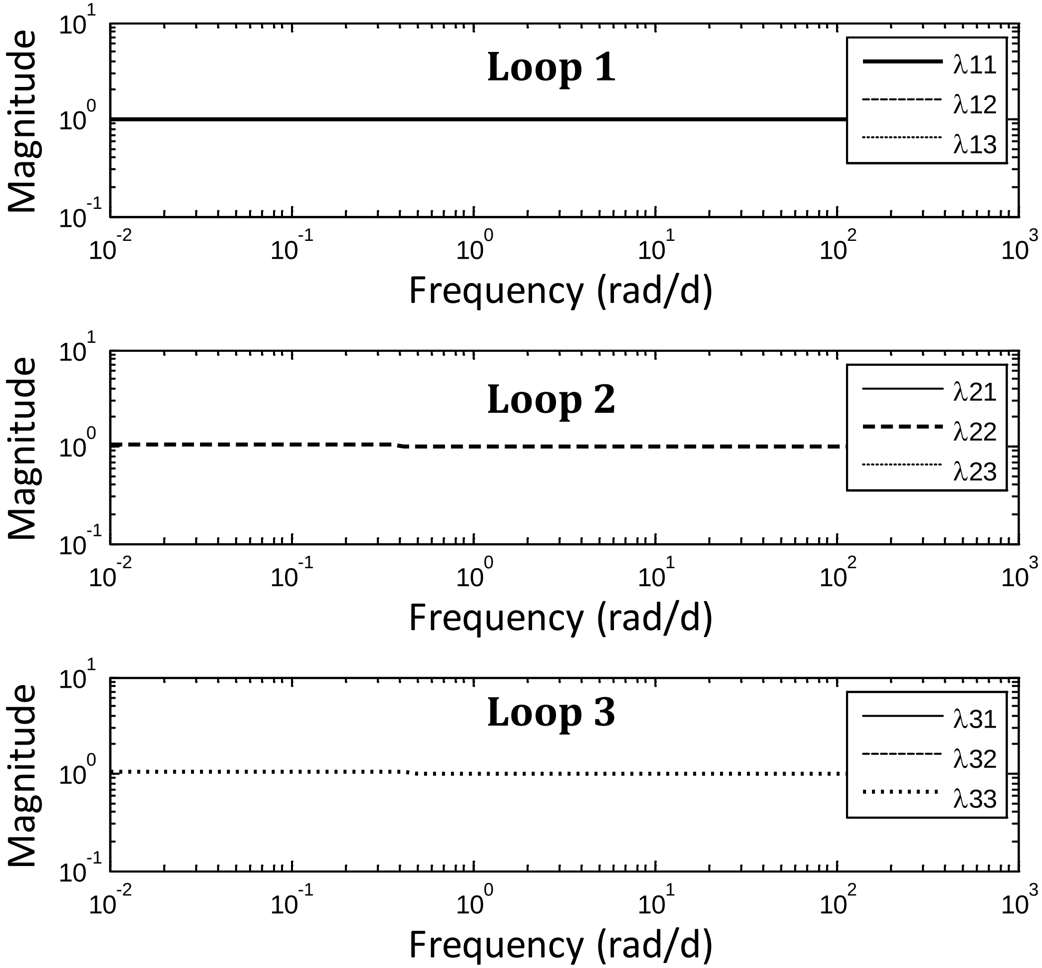
 Hovd and Skogestad 1994

Open loop assessment. Interactions

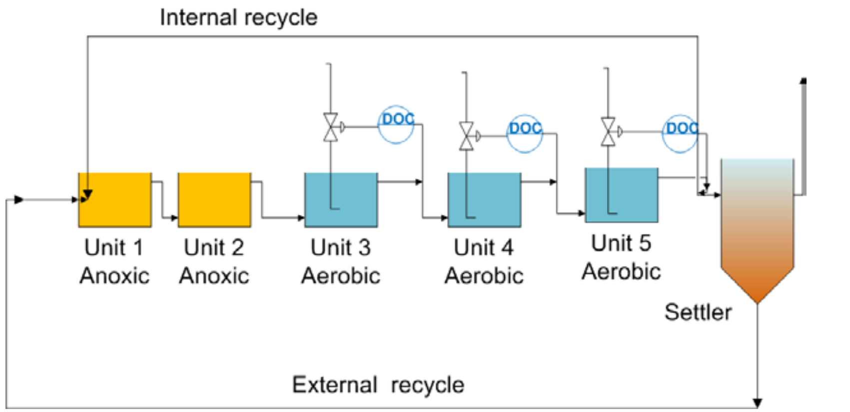
Relative Gain Array (RGA)

$$\lambda_{ij} = \frac{\left.\left(\partial y_i / \partial u_j\right)\right|_{u_k=0, k\neq j}}{\left.\left(\partial y_i / \partial u_j\right)\right|_{y_k=0, k\neq i}}$$

$$\lambda_{ij} = \frac{\text{Open loop gain}}{\text{Closed loop gain}}$$



Process review. Plant linearisation



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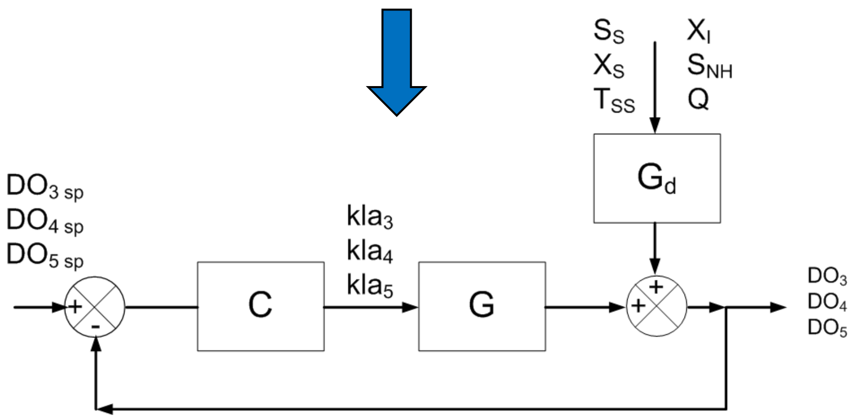
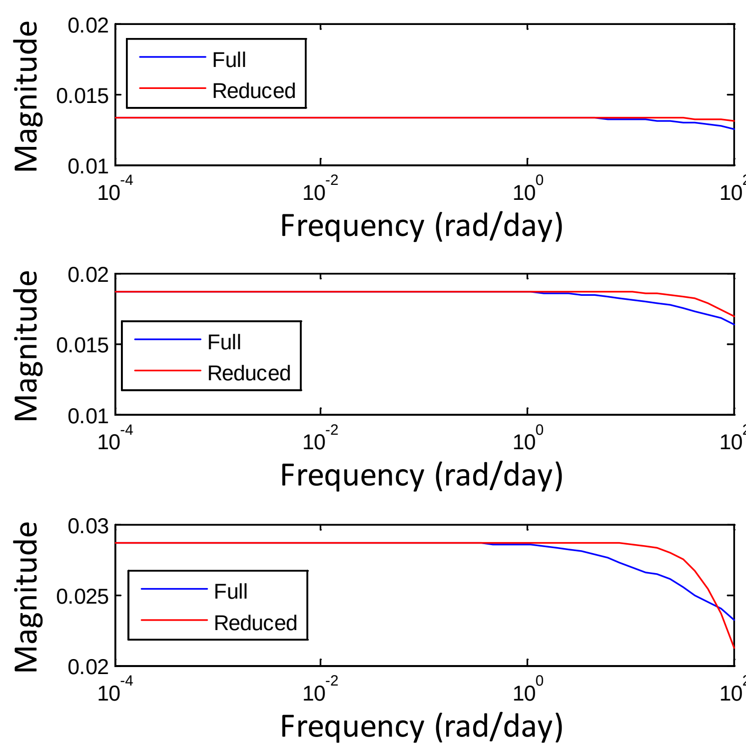




Full linear model (96 states)

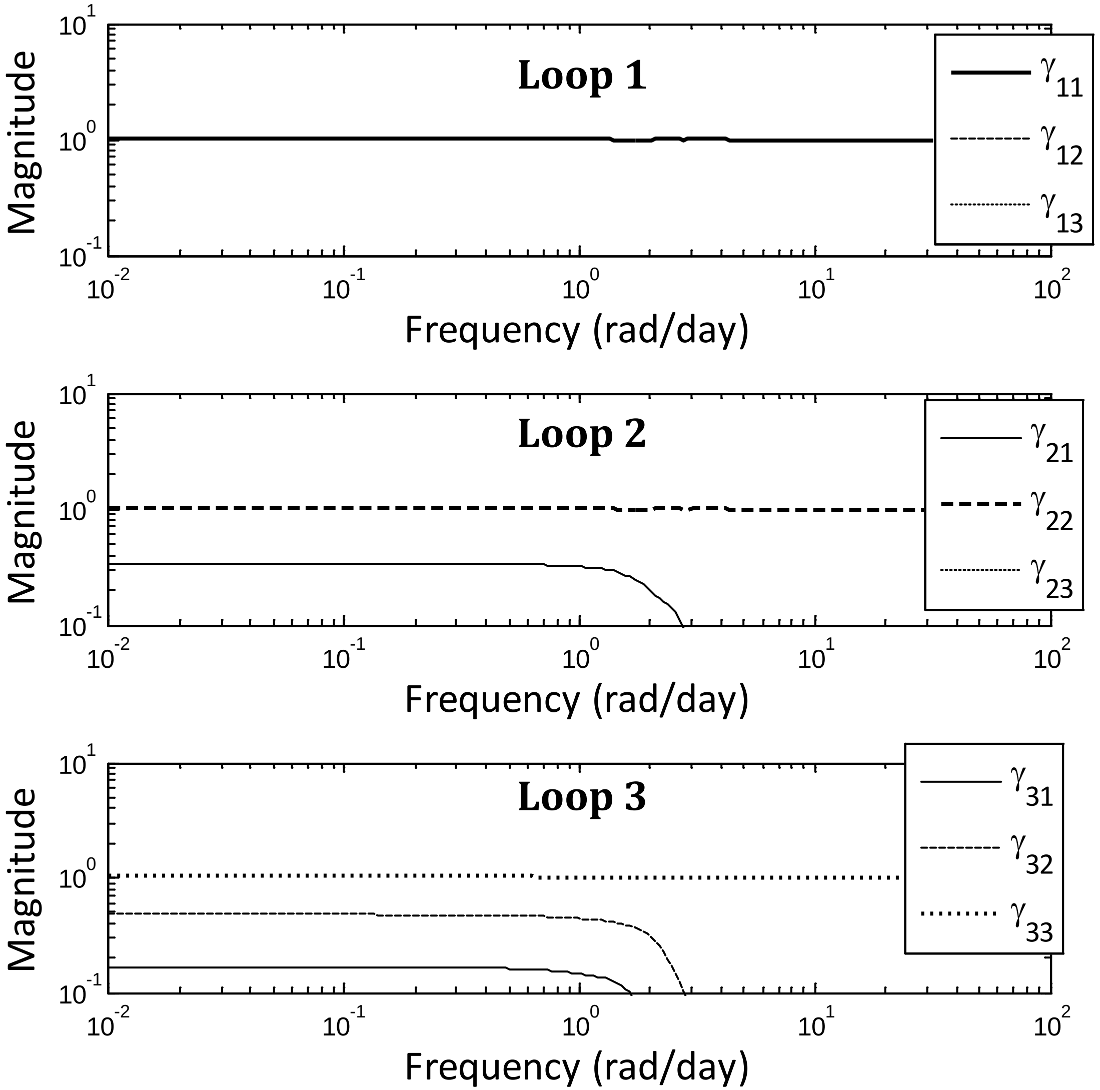
Reduced linear model (1 state)

Open loop assessment. Interactions

Performance Relative Gain Array (PRGA)

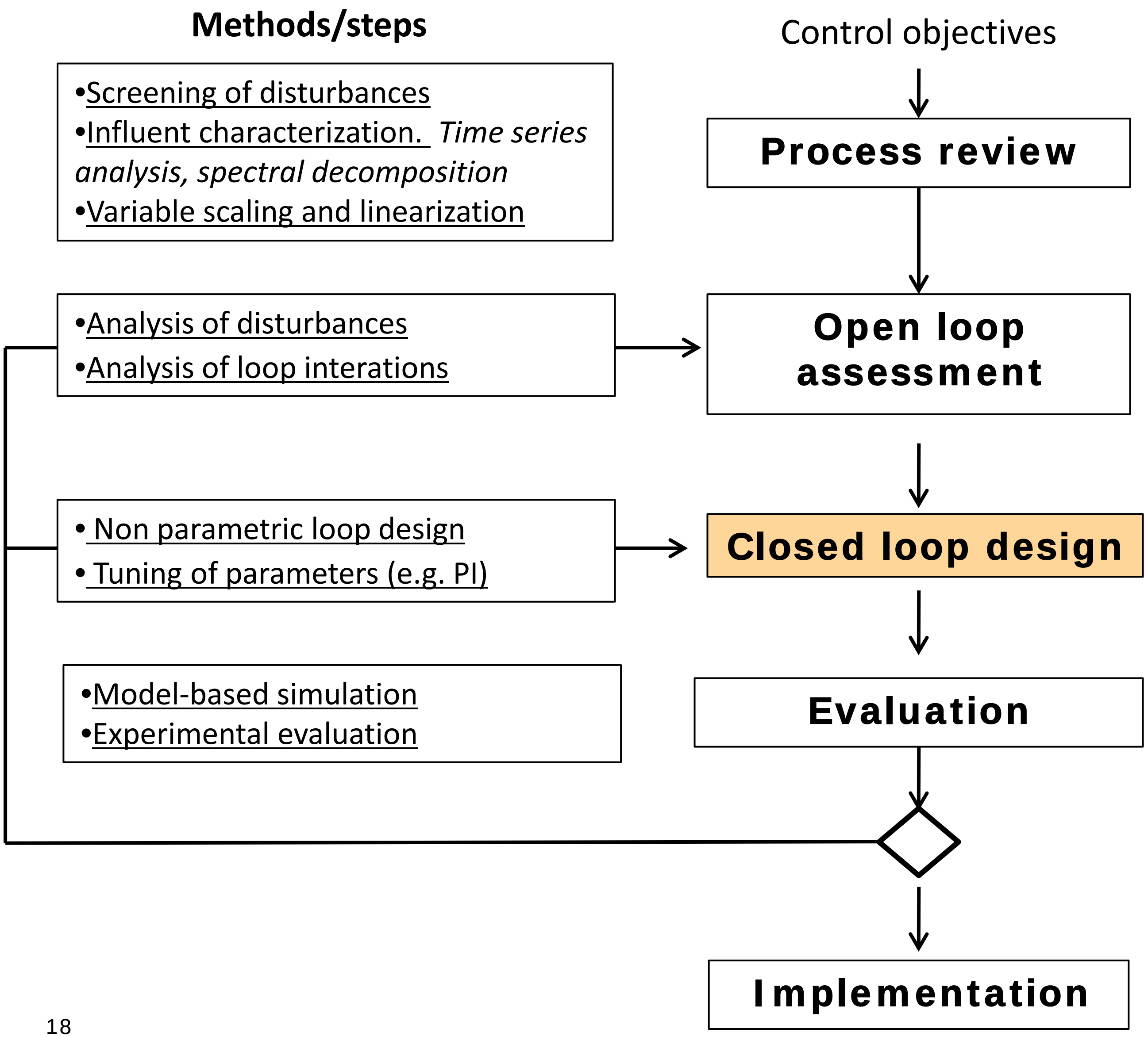
$$PRGA = \Gamma = \tilde{G}_{(s)} G^{-1}_{(s)}$$

- **Dependent on scaling**
- **Suitable for one-way interactions**

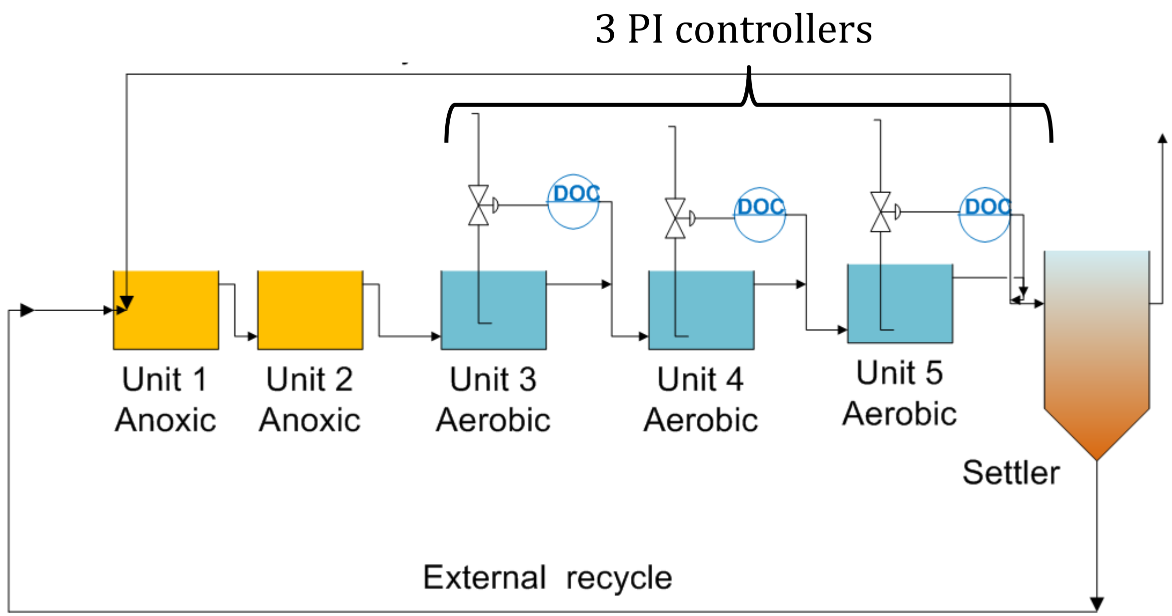


 Hovd and Skogestad 1992

Methodology



Closed loop design. Analysis of tuning parameters



Reported parameters Vanrolleghem and Gillot 2002

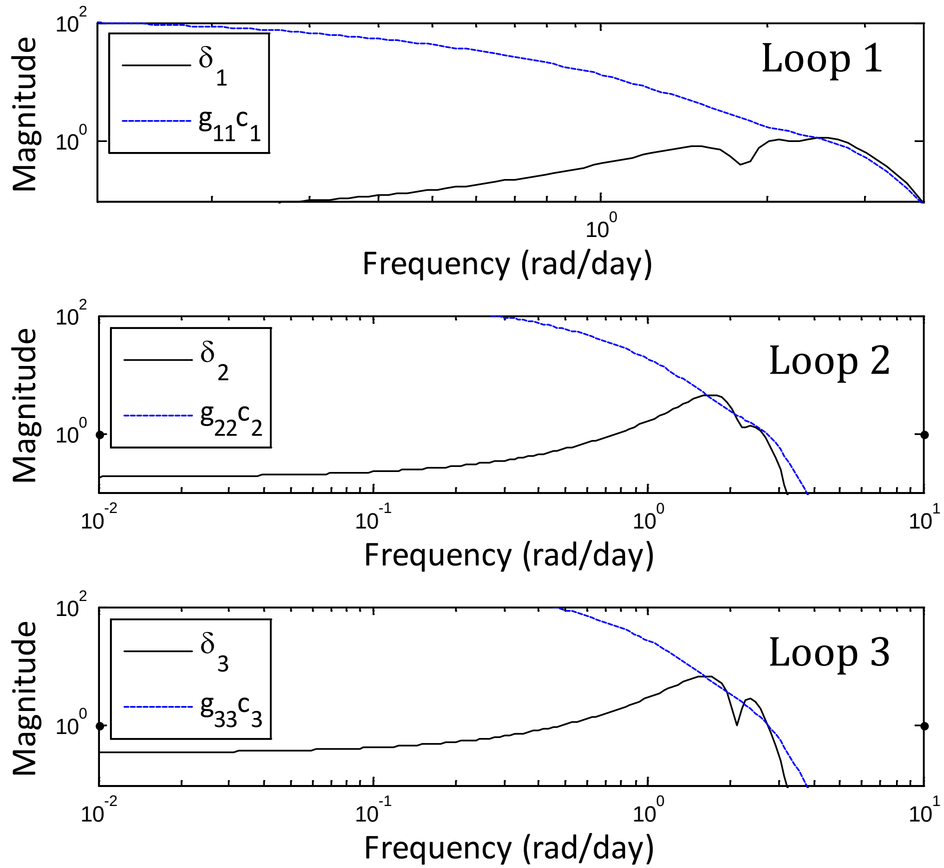
	Loop 1	Loop 2	Loop 3
$\mathbf{K_p}$	0.028	0.028	0.028
τ_I **(min)**	14.4	14.4	14.4

Closed loop design. Analysis of tuning parameters

CLDG = $|\delta_i| > 1$ at some frequencies

$|g_i c_i| > |\delta_i|$ **?**

CLDG for flow disturbance



 Hovd and Skogestad 1992

Closed loop design. New tuning parameters

$$\min |M_S|_\infty = f(K_p, \tau_I)$$

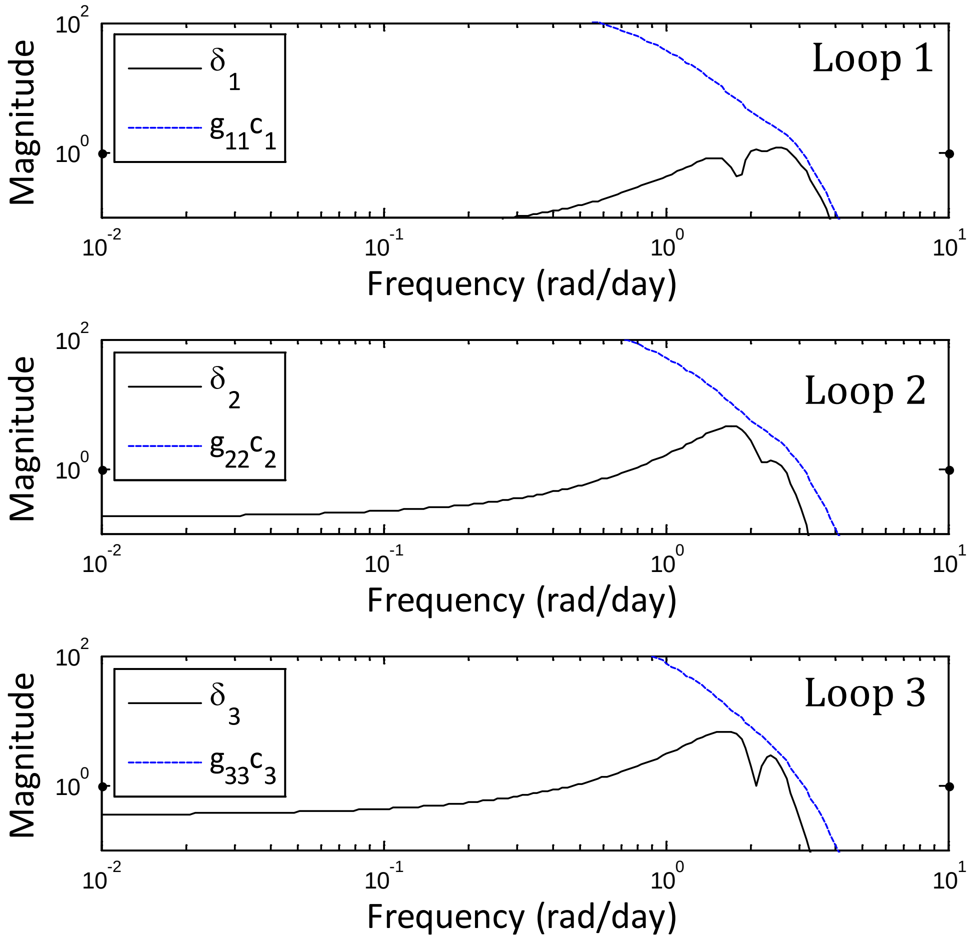
for $$S(s) = \frac{I}{I + G(s)C(s)}$$

s.t. $|g_i c_i| > 1.10\,|\delta_i|$ for $\omega < \omega_B$

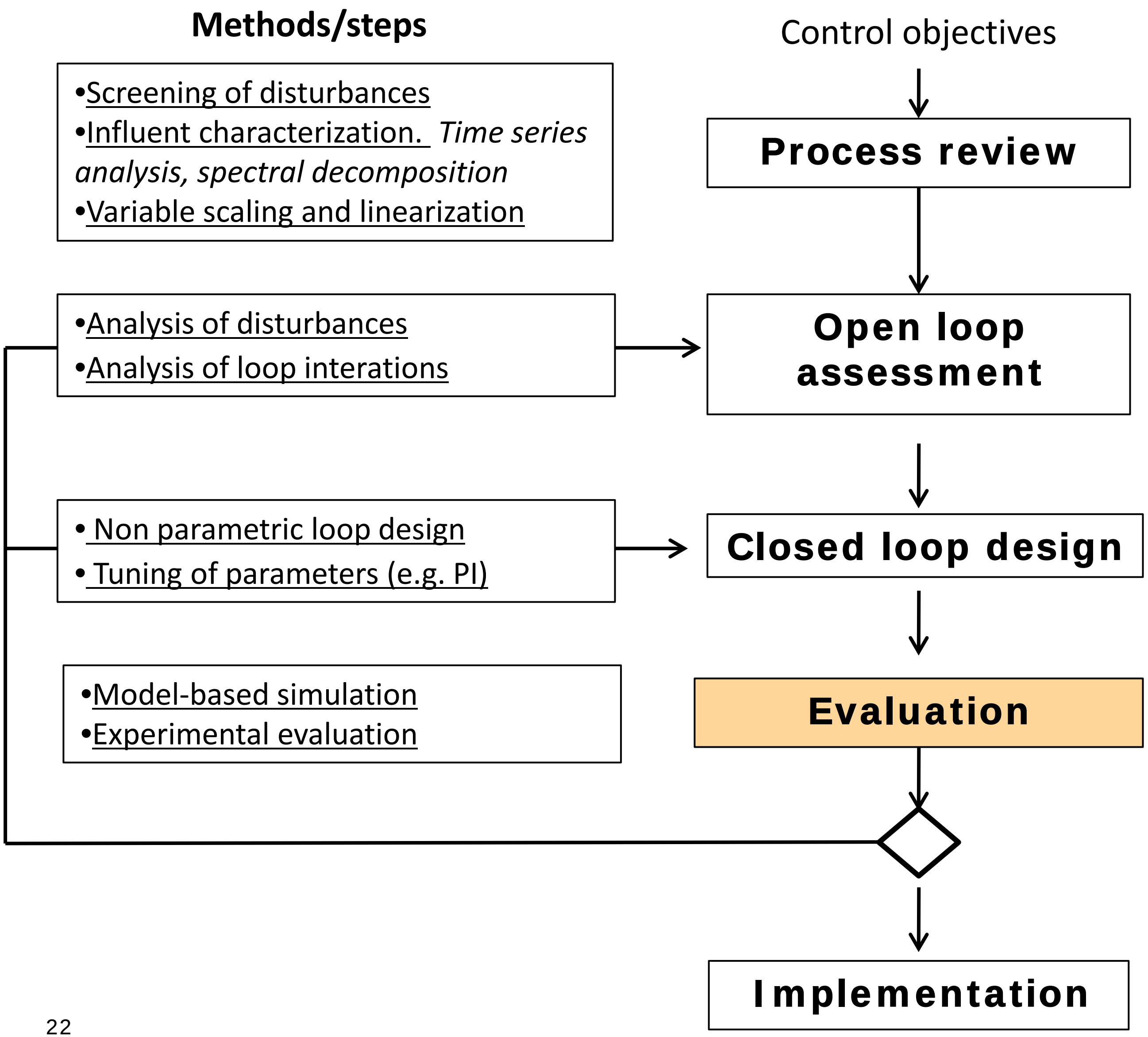
New parameters

	Loop 1	Loop 2	Loop 3
K_p	0.056	0.056	0.056
τ_I (min)	10.1	10.1	10.1

CLDG for flow disturbance



Methodology

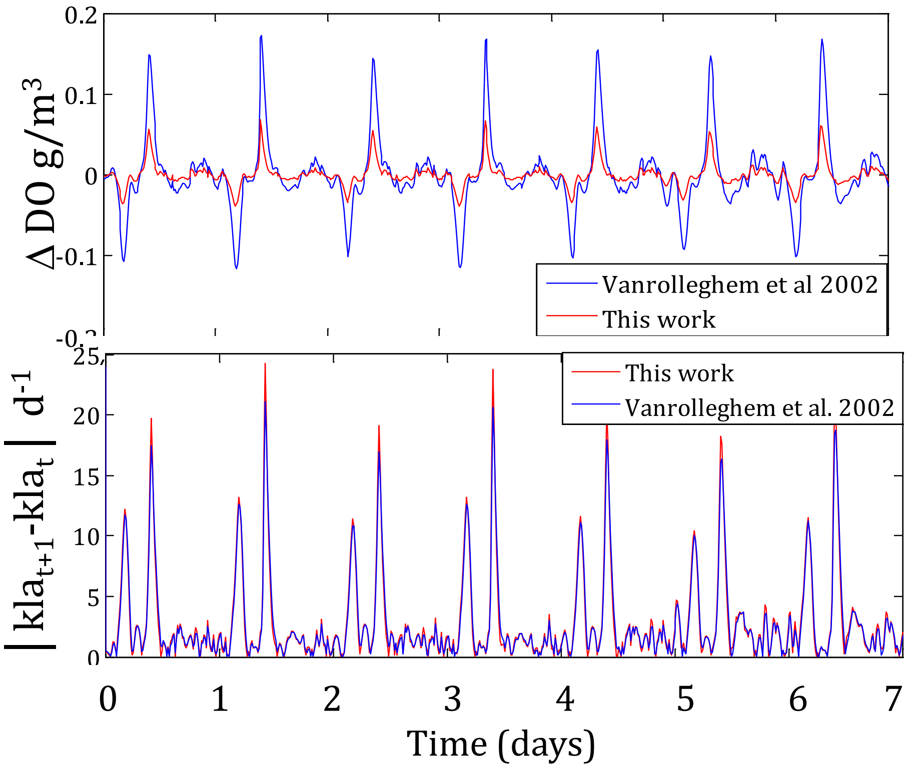


Evaluation

7 days dry weather + 7 days storm weather

$$IAE = \int_0^\infty |DO - DO^{sp}|\, dt$$

$$TV = \sum_{i=1}^{\infty} |kla_{i+1} - kla_i|$$



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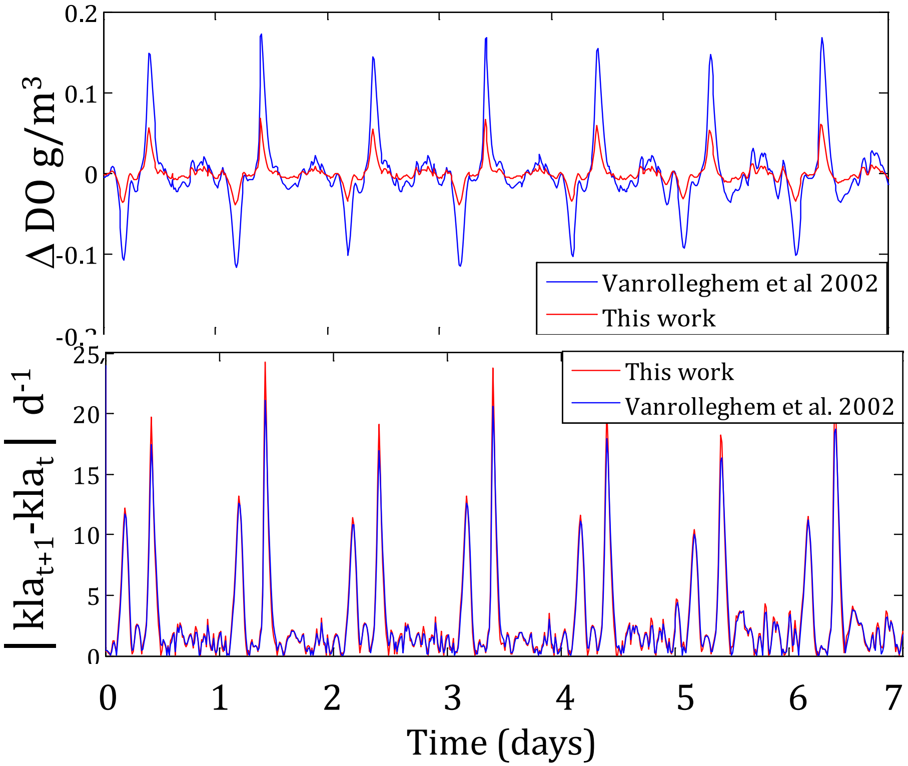

	Integral of absolute error (mgO_2 d L^{-1})			Total Variance of MV (d^{-1})		
	DO_3	**DO_4**	**DO_5**	**kLa_3**	**kLa_4**	**kLa_5**
Dryweather influent						
Vanrolleghem &Gillot$_{(2002)}$	0.190	0.326	0.315	14.0	31.5	31.3
This work	0.020	0.034	0.032	16.1	35.1	34.7
Storm weather influent						
Vanrolleghem &Gillot$_{(2002)}$	0.193	0.313	0.323	13.2	31.5	33.3
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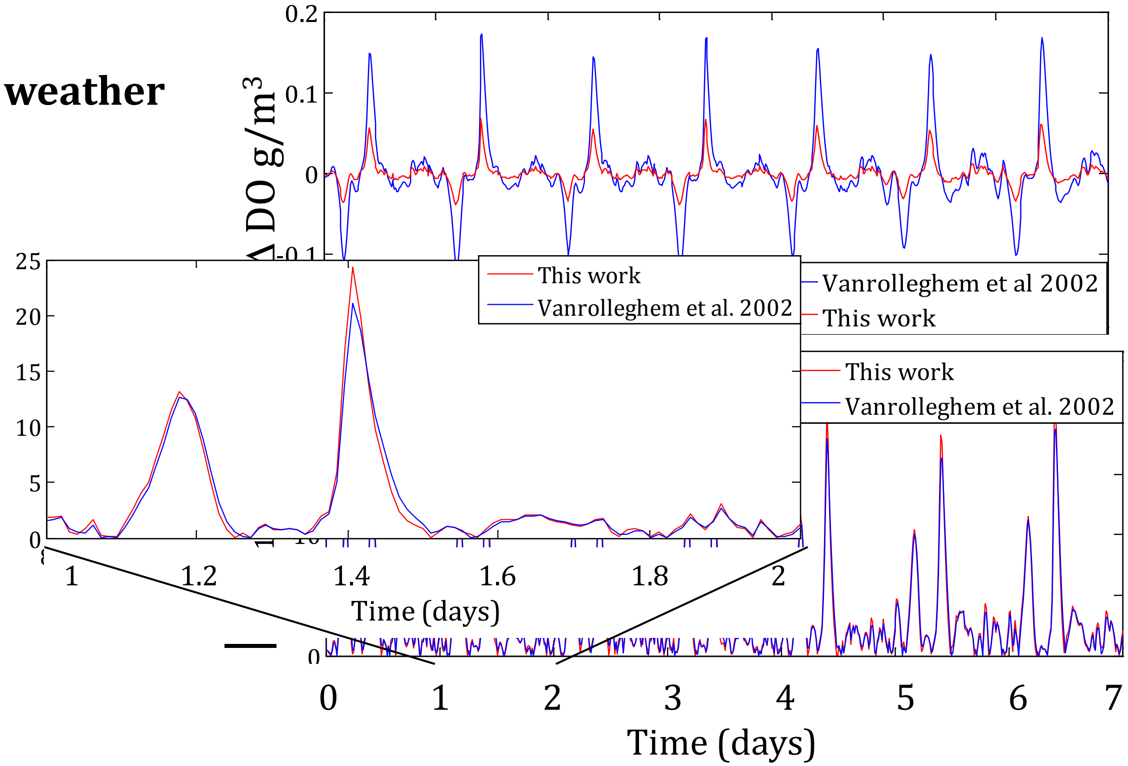

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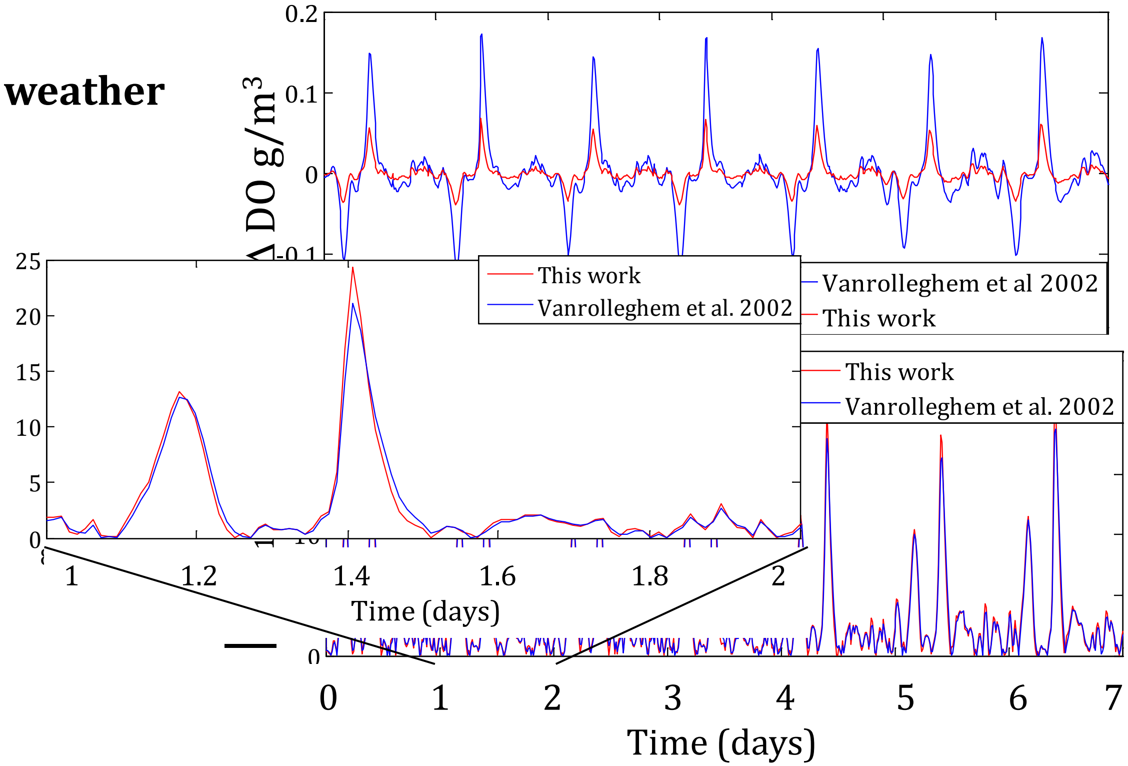

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Conclusions

We developed a **systematic methodology to formally approach** the tuning of controllers in WWTP

It takes into account the knowledge of **disturbances** in WWTP & user specified performance requirement (DCVs, deltaymax)

I**nformation about the inflow** is included to improve the tuning

It requires a model. Which is commonly used in WWTPs process design and operation.

It targets mainly existing plants but can be also used at design and planning stage.

The newly tuned controller showed **superior performance**

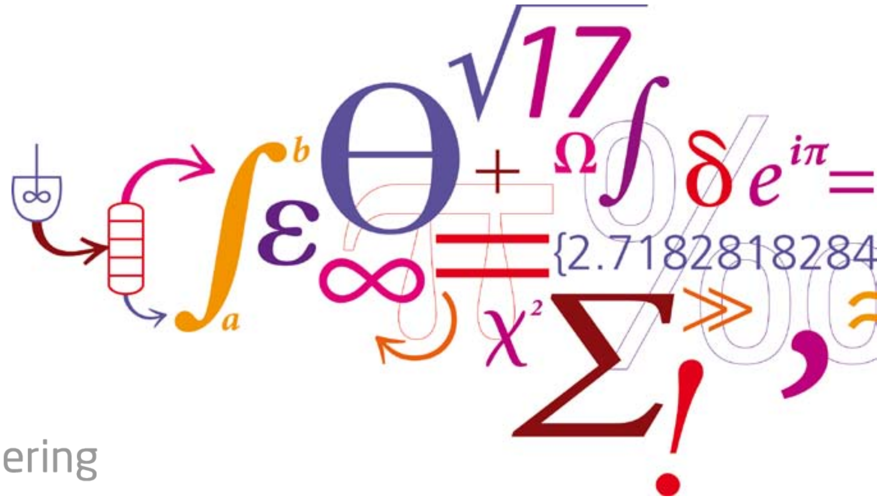
Some upcoming ideas…

Performance evaluation of the control structure including uncertainty, i.e. the combination of sensors and actuators, and how these relate to the control objectives

Controller tuning in wastewater treatment plants

Funded by Danish Agency for Science, Technology and Innovation through the Research Centre for Design of Microbial Communities in Membrane Bioreactors (09-067230) for funding of the project

Miguel Mauricio-Iglesias
Sten Bay Jørgensen
Gürkan Sin
mim@kt.dtu.dk



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